Influence of main site factors on *Fraxinus mandshurica* (Oleaceae) plantation

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Abstract: the investigation was carried out on 10-year-old plantation of *Fraxinus mandshurica* in Mao'er Mountain Experimental Station of Northeast Forest University. Tree height (H), diameter at breast height ($D_{1.3}$) and the increment of tree height in 5 years (H_5), the thickness of humus layer, as well as the soil moisture were measured for the plantation and the growth indexes (H, $D_{1.3}$, H_5) for different site conditions were analyzed. The results showed that main site factors influencing the growth of *Fraxinus mandshurica* were soil moisture, gradient and location of slope in order. The growth of *Fraxinus mandshurica* was better on the middle- or up-slope site than on the down-slope site. Soil moisture and late frost caused by terrain are the main reasons that limit the growth of *Fraxinus mandshurica* plantation.

Keywords: *Fraxinus mandshurica*; Plantation; Site factors
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Introduction

Fraxinus mandshurica (Oleaceae), manchurian ash, a precious broadleaved tree species in the northeast of China, mainly distributes in Xiaoxing'an Mountains and Changbai Mountain. *Fraxinus mandshurica* has good timber quality and beautiful texture. The natural forest of *Fraxinus mandshurica* has been about to be exhausted due to many years' successive cutting (The Resource Department of Forestry Ministry of China 1994), so that it is important to protect the plantation of *Fraxinus mandshurica*.

In the early 1980s, the plantation of *Fraxinus mandshurica* was established in Mao'er Mountain Experimental Station of Northeast Forest University. Now many plantations have been in closing stage. *Fraxinus mandshurica* trees planted in different sites present different growth status. This paper analyzed the effect of site factors on *Fraxinus mandshurica* plantation based on the survey conducted in 1996.

Study area

Study plots are located in Jianlagou Forest Research Station of Northeast Forestry University (127°30'-127°34'E, 45°21'-45°25' N), with upland physiognomy and an average altitude of 300 m. The climate is terrestrial monsoon. Annual average temperature is 2.8 °C and accumulated temperature (≥10 °C) is 2582.3 °C. Annual rainfall and annual evaporation are 723.8 mm and 1039.9 mm, respectively. Annual average relative humidity is 70%. The frost-free period is 120d, and the typical mountain soil is dark brown forest soil.

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Study methods

Investigation

The investigation was conducted in a pure plantation of *Fraxinus mandshurica* at age of 10, with 1.5 m×1.5 m initial spacing. Total of 31 temporary plots were set according to different slope orientation, slope gradient and slope location, and 30 sample trees were measured in each plot for tree height (H), diameter at breast height ($D_{1.3}$) and the increment in tree height in 5 years (H_5). At the same time, the thickness of humus layer and the soil moisture were also measured.

Data analysis

The plots were classified into different groups (in Table 1) and their distribution was shown in Table 2.

Dependent variables included tree height, diameter at breast height and the increment in tree height in 5 years. The different site factors were regarded as independent variables. The main factor that influence the growth of *Fraxinus mandshurica* was decided by using quantify model.

By analysis of variance and significance testing, the most suitable type of site for *Fraxinus mandshurica* growth was determined.

Results and analysis

Establishing model for *Fraxinus mandshurica* based on the site factors

The mean values of each dependent variable (tree height, diameter at breast height and the increment of tree height in 5 years) and the quantified or actual value of each site factor (independent variable) were use for set up the model.

Quantified model were used to simulate the data. The result is as follows:

$$H=2.1718+0.14481\delta_{1\text{-}1}-0.5134\delta_{1\text{-}2}+0.0830\delta_{1\text{-}3}+0.4775\,\delta_{2\text{-}1}+0.4209\delta_{2\text{-}2}-0.25164\delta_{3\text{-}1}-0.5332\delta_{3\text{-}2}+0.1278\delta_{3\text{-}3}+1.2928\delta_{4\text{-}1}+0.1587\delta_{4\text{-}2}-0.0516\delta_5 \quad (1)$$

$$H_5=2.3582-0.2001\delta_{1\text{-}1}-0.61124\delta_{1\text{-}2}-0.2155\delta_{1\text{-}3}+3053\delta_{2\text{-}1}+1145\delta_{2\text{-}2}-0.2844\delta_{3\text{-}1}-0.3104\delta_{3\text{-}2}+0.3033\delta_{3\text{-}3}+1.0749\delta_{4\text{-}1}+0.1439\delta_{4\text{-}2}-0.0226\delta_5 \quad (2)$$

$$D_{1.3}=1.7973+0.0434\delta_{1\text{-}1}-0.3243\delta_{1\text{-}2}+0.2240\delta_{1\text{-}3}+0.5187\delta_{2\text{-}1}+2240\delta_{2\text{-}2}+0.0261\delta_{3\text{-}1}-0.1787\delta_{3\text{-}2}-0.1507\delta_{3\text{-}3}+1.4191\delta_{4\text{-}1}+0.2680\delta_{4\text{-}2}-0.0369\delta_5 \quad (3)$$

Where: δ_1 is aspect of slope; δ_2 is slope location; δ_3 is gradient slope; δ_4 is soil moisture; δ_5 is soil thickness of layer A; H is tree height; H_5 is the increment of tree height in 5 years; $D_{1.3}$ is diameter at breast height.

Table 1. Grade of site factors

Grade of site factor	Aspect of slope	Slope location	Gradient slope (°)	Soil moisture	Soil thickness of layer A
4	North	—	≥20	—	—
3	West	Down	15-19	Wet or drought	—
2	South	Middle	10-14	Middle moisture	—
1	East	Up	<10	Moisture	—

Note: The thickness of humus layer is actually value.

The coefficients of multiple correlations for model (1), (2) and (3) is 0.9302, 0.9319 and 0.9078 respectively, which show a high level of significance *i*. The partial correlation coefficient and the *t*-value of testing between site factors and the index of tree growth are listed in Table 3.

When $T>1.0$, the considered factor has influence on the dependent variable; when $T>2.0$, the considered factor has greater influence on the dependent variable (Wang 1990).

According to Table 3, for tree height (H), the sequence of site factor's importance is: soil moisture, gradient, location on slope, slope orientation, soil humus layer thickness; for the increment of tree height (H_5), the sequence is: soil moisture, gradient, slope orientation, location on slope, soil humus layer thickness; and for diameter ($D_{1.3}$), it was soil moisture, location on slope, gradient, slope direction and soil humus layer thickness.

To sum up, the key factors influencing the growing of *Fraxinus mandshurica* are soil moisture, slope gradient and slope location.

Table 2. The number of plots in every site factor

Grade of site factor	Aspect of slope	Slope location	Gradient slope	Soil Moisture
1	12	10	9	10
2	3	10	12	10
3	13	11	6	11
4	3	—	4	—

The site factor's influence on growth of *Fraxinus mandshurica*

Soil moisture

Soil moisture directly influences the activity of root. Proper proportion of liquid, solid and gas can enhance the root to absorb substance (Northeast Forestry University 1982). When there is too much water in soil, it will reduce oxygen content, obstruct root in breathing and absorbing nutrient substance, and even bring root to decompose (Ge *et al.* 1991; Li *et al.* 1991).

Table 3. Significance test of the partial correlation coefficient

Site factor	Partial correlation coefficient			*t*-value		
	H	H_5	$D_{1.3}$	H	H_5	$D_{1.3}$
Aspect of slope	0.4825	0.46221	0.4210	2.75**	2.61*	2.32*
Slope location	0.5455	0.37826	0.5124	3.25**	2.08*	2.98**
Gradient slope	0.5509	0.5630	0.2553	3.30**	3.41**	253**
Soil moisture	0.8194	0.8237	0.8626	7.15**	7.26**	8.52**
Soil thickness of layer A	-0.4636	-0.2655	-0.3475	2.62*	1.37	1.85

Notes: ** and * respectively represent significantly different in 99% and 95%. $T_{0.05}=2.04$, $T_{0.01}=2.75$; H---- Tree height; H_5---- the increment of tree height in 5 years; $D_{1.3}$----diameter at breast height.

The tree growing state was compared under 3 kinds of soil moisture (Fig. 1). The trees on the moist sites were better in growth than those on the middle moist, very wet and drought sites in the H, H_5, and $D_{1.3}$. The maximum gap in height between the different sites is 1.6 m.

The analysis of variance was conducted on 3 types of soil moisture: moist, middle moist, wet or drought (Table 4).

Table 4. Analysis of variance in different soil moistures

Index of growing	Source of variance	Degree of freedom	Sum of square	Mean of square	*F*-value	*F* (0.05)
	Grouping error	2	15.052 4	7.526 2	22.53*	3.34
H	Inner-group error	28	9.351 1	0.334 1		
	Sum error	30	24.403 5			
	Grouping error	2	9.833 1	4.916 6	22.68*	3.34
H_5	Inner-group error	28	6.069 1	0.216 8		
	Sum error	30	15.902 2			
	Grouping error	2	11.985 6	5.982 8	26.20*	3.34
$D_{1\,3}$	Inner-group error	38	6.304 3	0.228 4		
	Sum error	30	18.289 9			

More comparisons were done in the different levels. Results showed that the differences between all levels are significant, which approve the fact that soil moisture has influences on growth of *Fraxinus mandshurica*.

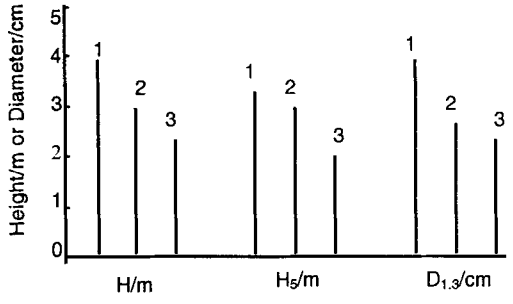

Fig. 1 The comparison of the tree height and diameter in different soil moistures
1: Moist; 2: Middle moist; 3: Wet or drought

Slope location

Soil moisture and nutrition content are different with the different slope locations. In our experiments, we divided the slope into three sections: up-slope, middle-slope, down-slope. The growth status of trees on the different sections of slope was shown in Fig. 2. The results by analysis of variance are listed in Table 5.

From the Fig. 2, we could see the fact that the growth status of trees on different sections of slope is significant different. The trees on up-slope section grew best, followed by those on middle-slope, and the tree growth on down-slope section is the worst.

The difference in tree growth between the up-slope and the middle-slope and down-slopes was significant but was not significant between middle-slope and down-slope (Table 6). Therefore it is concluded that in the study region, *Fraxinus mandshurica* trees on up-slope is better in growth than those on middle- and down-slope. The proceeding study reported that *Fraxinus mandshurica* prefer on middle- and down-slope sites (The Resource Department of Forestry Ministry of China 1994). There are two main reasons for these differences. One reason is that our studied plantation lies in the slope between two mountains, where the later frost raids the plant, and the other is that down-slope is flatter than up-slope and drainage is not very well.

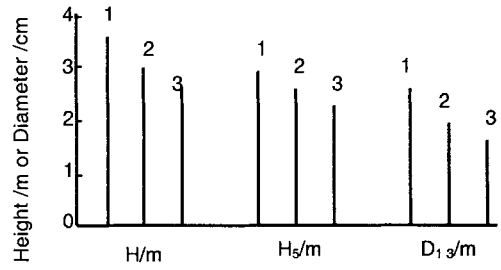

Fig. 2 the comparison of tree height and diameter in different slope locations
1: up-slope; 2:middle-slope; 3:down-slope

Gradient of slope

The gradients of slope were classified into 4 grades, <10°, 10°-14°, 15°-19°, and ⩾20°. *Fraxinus mandshurica* trees grew better on the site with a gradient of >15°, compared to those on the site of <15°, grew best on the site with a gradient of 15°-19° but worst on the site with a gradient of <10° (Fig. 3). One-way analysis of variance was made for the different degrees of gradient. The result showed that the difference is significant. Because the gradient of up-slope is bigger than that of down-slope in our plot, the result is the same as the analysis of location of slope.

Slope aspect

Because of the difference of sunlight angles, intensity of radiation and the time of shining in the different direction, the conditions of water and heat are different and the substance accumulation by photosynthesis is also influenced.

The result analysis showed that the growth of *Fraxinus mandshurica* was not significantly different in all the sites. The reason is the fact that the plantation was established in the strip of natural forest where all tree was cut. The function of slope directions was concealed by the function of tree wall, which changed the distribution of sunlight.

Thickness of humus layer

Humus layer contains much organic matter. It is a main pool for tree absorbing nutrient. Usually the thicker the humus layer is, the more the fertilizer contains in soil (Tang 1986).

There exists significantly negative relation between the three indexes of *Fraxinus mandshurica* (H, H_5 and $D_{1.3}$) and

thickness of soil humus layer. The coefficients of H, H_5 and $D_{1.3}$, were -0.4636, -0.2655 and -0.3475749, respectively. Those results are attributed to temperature inversion and landform. The soil on down-slope successively accumulates and forms a thicker humus layer. At the same time, for even flatter, the surface of soil is covered by seasonal water. In our plots, the period of the surface of soil covered by water is in July and August, when the rainfall is biggest. As a result the growth of tree is retarded. Moreover, the annual later frost made the shoot growing on the thicker humus layer frozen. The increment of growth decreased.

Table 5. Analysis of variance in different slope location

Index of growing	Source of variance	Degree of freedom	Sum of square	Mean of square	*F*-value	*F*(0.05)
Tree height	Grouping error	2	6.8033	3.4917	5.42*	3.34*
	Inner-group error	28	17.6041	0.6287		
	Sum error	30	24.4074			
Increment of height in 5 years	Grouping error	2	4.2154	2.1070	5.05*	3.34*
	Inner-group error	28	11.6869	0.4173		
	Sum error	30	15.9023			
Diameter at breast height	Grouping error	2	4.5326	2.2663	4.59*	3.34*
	Inner-group error	38	13.8273	0.4938		
	Sum error	30	18.3599			

Note: ** and * respectively represent significantly different in 99% and 95%.

Table 6. The post hoc comparisons in different locations slope of location

Index of growth	Slope location	Middle-slope	Down-slope
H	Up-slope	0.86**/(0.73-0.93)	1.09**/(0.71-0.91)
	Middle-slope		0.23/ (0.71-0.91)
H_5	Up-slope	0.70**/(0.48-0.62)	0.85**/(0.47-0.60)
	Middle-slope		0.15/ (0.47-0.60)
$D_{1.3}$	Up-slope	0.71**/(0.57-0.73)	0.89**/(0.56-0.71)
	Middle-slope		0.18/ (0.56-0.71)

Notes: ** and * respectively represent significantly different in 99% and 95%; H ----Tree height; $D_{1.3}$----diameter at breast height; H_5----the growth height in recent 5 years.

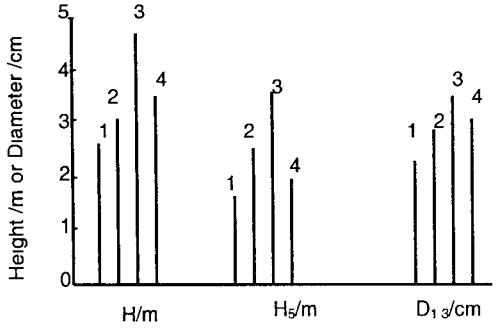

Fig. 3 The comparison of tree height and diameter in different slope gradients
1:<10°; 2:10°-14°; 3:15°-19°; 4:≥20°

Conclusions and discussion

According to the investigation and analysis, the soil moisture, gradient and location of slope make different degrees of influence on the growth of *Fraxinus mandshurica*. The order is soil moisture>gradient> location of slope. The best site for growth of *Fraxinus mandshurica* is up-slope with a gradient of ≥15°, and the worst site is down-slope or more plain area.

As the average altitude of the study plot is lower, the extension of temperature degrading and soil thickness changing is small. Moreover, because there exists difference in temperature and gradients between up-slope and down-slope, the ecological factors are redistributed. So, the conclusion may be different from that we have drawn. According to our study results, the ecological scope of soil moisture and temperature for growth of *Fraxinus mandshurica* is narrower. The selection of site should be highly noticed when establishing the plantation of *Fraxinus mandshurica*.

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